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ORIGINAL PAPER

Decomposition and nutrient release patterns of *Phyllostachys bambusoides* and *Arundinaria racemosa*, India

K. Upadhyaya • A. Arunachalam • K. Arunachalam • A.K. Das

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Abstract: We investigated decomposition and nutrient release patterns of leaf and sheath litter of two important highland bamboo species (*viz*. *Phyllostachys bambusoides* Sieb. (Zucc.) and *Arundinaria racemosa* Munro) by using a litter bag technique. Our objective was to improve understanding of the addition of organic matter and nutrients to soil from the litter of two abundant highland bamboo species, species that support the local population of the region in many ways. N concentration and N/P ratio were significantly higher (p<0.01) in leaf litter of *P. bambusoides*. Significantly, larger values of lignin concentration, C/N ratio, and lignin/N ratio were found in the sheath litter of *A racemosa*. Weight loss of both leaf and sheath litter was strongly positively correlated with N and N/P ratio, and significantly negatively correlated (p<0.01) with C/N ratio. Lignin/N had a negative correlation with decay rate. In both species, only lignin concentration of the litter showed strong positive correlation with N release. Litter decomposition and N release patterns were similar for the two bamboo species, whereas, P release rate from leaf litter was higher in *P. bambusoides* and differed significantly between sheath and leaf litter for both species. The complex pattern of nutrient release through mineralization and immobilization during litter decomposition ensures nutrient availability in both managed and natural bamboo stands subjected to anthropogenic disturbances.

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K. Upadhyaya (✉)
Department of Forestry, Mizoram University, Aizawl–796004, Mizoram, India. E-mail: kalidaskhanal@yahoo.com

A. Arunachalam
Department of Agro-Forestry, ICAR, PUSA, New Delhi–110012, India.

K. Arunachalam
Department of Forestry, North Eastern Regional Institute of Science and Technology, Nirjuli–791109, India.

A.K. Das
Department of Botany, Rajiv Gandhi University, Rono Hills, Doimukh, Itanagar–791111, India.

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Introduction

Bamboo with its varied uses has historically been an integral part of livelihoods and life-styles in northeast India. Bamboo forests and plantations in this part of the country are mainly grown in nutrient poor soils and are subjected to heavy biomass removal through bamboo harvest. Therefore, maintaining the organic pool and nutrient budget in these resource-poor bamboo forests is essential for sustained productivity that depends mainly on the recycling of nutrients contained in bamboo litter. Bamboo flowering has been considered a nuisance caused by some species because it adds volumes of foliage litter to the soil after flowering. This has increased research attention to the role of bamboo litter in maintenance of soil organic matter content and nutrient levels. Nutrient release from litter decomposition may play an important role in nutrient cycling in nutrient poor soils, particularly when the ecosystem is undergoing recovery following disturbance (Arunachalam and Arunachalam 2002).

Decomposition of and nutrient release by leaf litter are important processes governing organic matter accumulation and forest ecosystem functioning (Swift et al. 1979). Nutrients are not merely soil characteristics, but are a function of inputs from the organic and elemental cycling of vegetation (Menaut et al. 1985). Although the release rate of nutrients from litter is generally governed by the rate of decomposition, different nutrients may be released at different rates and may exhibit differential release patterns (Garkoti and Singh 1999). Litter decomposition is mainly governed by two factors, climate (rainfall, temperature, actual evapotranspiration) and the initial substrate quality of the litter (Swift et al. 1979; Berg et al. 1993). Plant litter on substrates of varying quality can exhibit different mineralization potentials and decomposition patterns (Mtambanengwe and Kirchman 1995). Among the initial litter quality variables, water or ethanol soluble substances, cellulose, lignin and nitrogen (N)

content, and ratios of C/N and lignin/N play important roles at different stages of litter decomposition (Taylor et al. 1989; Tripathi and Singh 1992a and 1992b; Tripathi et al. 2006).

Although many studies have investigated litter decomposition and nutrient dynamics, most of those studies concentrated on coniferous and broad-leaved forests. Investigation of litter decomposition in bamboo forests and subsequent release of nutrients are few (Fu et al. 1988; Tripathi and Singh 1992a and 1992b; Liu et al. 2000; Sujatha et al. 2003; Deb et al. 2005; Nath and Das 2011). Understanding the decomposition dynamics of bamboo litter can help to formulate efficient management tools for maintaining productivity of these important plant resources. Our study objectives were to understand the decay patterns and nutrient (N & P) release rates of leaf and sheath litter of two important and abundant highland bamboo species, *viz.*: *Phyllostachys bambusoides* Sieb. (Zucc.) and *Arundinaria racemosa* Munro, in India. Both species support the local populations and economies of the region in many ways. For example, both the species are used by the local Apatani and Monpa communities for house construction, fencing, for making handicraft items and also young shoots are consumed as vegetables.

Materials and methods

Study sites

We studied *P. bambusoides* plantations in the Ziro valley (27°30' N, 93°50' E and 1,700 m asl) of Lower Subansiri district and *A. racemosa* stands in the Jang area (27°31' N, 92°00' E and 3,000 m a.s.l.). *P. bambusoides* is grown in managed plantations, whereas, *A. racemosa* grows naturally. Both species are harvested by local people for meeting various household needs, such as construction of housewalls, floors and roofs, fencing, agricultural tools, basketary items for grain storage, food items (young shoots), etc. The climatic, physiographic and edaphic characteristics of the study sites are shown in Table 1.

Sampling and analytical procedures

Freshly, fallen leaves and sheaths of the two bamboo species were collected from the study sites during March. Litter was collected and airdried from five replicated clumps for the sympodial species (*A. racemosa*) and from five replicated quadrats (10 m × 10 m) for the monopodial *P. bambusoides*. The litter samples from different clumps and quadrats for each species and category were mixed to form four categories of samples (2 species × 2 litter types). Air-dried litter samples equivalent to 10 g of oven-dry weight were placed in nylon litter-bags (1 mm mesh; 15 cm × 15 cm). Sixty bags were prepared for each litter fraction for each species. The bags were equally distributed in five clusters on both study sites. In order to avoid disturbance by grazing animals, the bags were buried in the top 0–5 cm soil layer during March. Five bags per litter type were retrieved at 60 day intervals. Sample from each bag were then cleaned of adhering plant parts and soil particles, oven-dried at 105°C for 24 h, and weighed.

Table 1. Physiographic, climatic and edaphic characteristics of study sites.

Parameters	Study sites	
	Ziro	Jang
Physiography		
Latitude	27°30′ N	27°31′ N
Longitude	93°50′ E	91°55′ E
Altitude (m asl)	1700	3000
Slope (%)	2–5	25–60
Aspect	North-West	North-West
Climate		
Annual rainfall (mm)	1545±82.6	2000±77.3
Air temperature (°C)		
Maximum	30.6±2.54	19.3±2.11
Minimum	4.0±0.87	2.3±0.89
Relative humidity (%)	42±2.58	62±3.61
Edaphic characteristics		
Textural class	Loamy sand	Loamy sand
WHC (%)	76.81±2.21	47.63±1.37
Bulk density ($g \cdot cm^{-3}$)	0.60±0.04	0.72±0.02
pH (1:2.5 w/v H_2O)	5.21±0.16	4.90±0.11
Soil organic C (%)	3.85±0.18	1.47±0.10
Total N (%)	0.70±0.05	0.24±0.06
Available P ($\mu g \cdot g^{-1}$)	20.76±0.24	9.70±0.20
C/N	5.50	6.13

± SE

Subsamples of litter were oven-dried at 105°C for 24 hours to determine their dry weights and for moisture correction, and were then retained for chemical analyses. The oven-dried litter samples were ground in a Willeymill and passed through a 0.5 mm mesh sieve for chemical analyses. Ash content of litter was determined by igniting ground samples in a Muffle furnace at 550°C for 6 hours. Carbon (C) content was calculated by taking 50% of ash-free weight (Allen et al. 1974). Total N was determined by the semi-micro Kjeldahl procedure with phenolphthalein as the indicator. Total P was estimated colorimetrically using Olsen's molybdenum blue method (Anderson and Ingram 1993). Lignin and cellulose contents were determined using the acid detergent fibre method, and the fibre content was measured gravimetrically (Anderson and Ingram 1993).

Computation and statistics

Organic matter decay constants were computed using the negative exponential decay model of Olson (1963):

$$\frac{X}{X_0} = \exp(-kt) \tag{1}$$

where, X is the weight remaining at time of t, X_0 is the initial weight, exp is the base of natural logarithm, k is the decay rate coefficient and t is time.

Further, the time required for 50% (t_{50}) and 99% (t_{99}) decay was calculated as t_{50}=0.693/k and t_{99}=5/k. Similarly, release rates of N and P were computed as the product of remaining dry mass and respective nutrient concentrations. The nutrient (N and P) release constants (k_N and k_P) were computed by Equ. 1. In this calculation, X is the nutrient remaining at time of t, X_0 is the initial nutrient content, exp is the base of natural logarithm, k is the nutrient release rate coefficient and t is the time. The time required for 50% (t_{50}) and 99% (t_{99}) N and P mineralization were also calculated as t_{50}=0.693/k and t_{99}=5/k.

The effect of initial litter chemistry and rainfall of the respective study sites on decay rate and nutrient release rate was tested by the linear regression function, the format is similar as $Y = a+bX$. Multiple comparison tests were used to compare the means between litter types and species.

Results

Initial litter quality

N concentration was greater in *P. bambusoides* litter and C/N ratio was greater in *A. racemosa* litter. Leaves of *A. racemosa* had greater concentrations of C and P. Except between sheaths of the same species, lignin concentration and lignin/N ratio showed no significant differences between litter types (Table 2). In general, C/N, lignin/N, C/P and lignin/P ratios were greater in sheath litter, whereas N/P ratio was greater in leaf litter.

Table 2. Litter quality of *P. bambusoides* and *A. racemosa*

Residue Quality	*P. bambusoides* Leaf	*P. bambusoides* Culmsheath	*A. racemosa* Leaf	*A. racemosa* Culmsheath
C (%)	42.46^a	47.22^b	47.80^b	44.70^c
	(0.026)	(0.032)	(0.017)	(0.017)
N (%)	1.22^a	0.67^b	1.03^c	0.49^d
	(0.091)	(0.084)	(0.067)	(0.044)
P (%)	0.086^a	0.058^b	0.093^a	0.056^b
	(0.005)	(0.003)	(0.005)	(0.006)
Lignin (%)	24.91^a	25.61^a	25.96^a	37.19^b
	(1.90)	(1.90)	(1.64)	(2.37)
Cellulose (%)	41.22^a	42.48^a	48.42^b	44.67^c
	(0.632)	(0.801)	(1.215)	(0.854)
Fibre (%)	30.10^a	31.02^a	35.20^b	33.13^c
	(0.528)	(0.556)	(1.069)	(0.704)
C/N	34.80^a	70.48^b	46.41^c	91.22^d
Lignin/N	20.42^a	38.22^b	25.20^c	75.90^d
N/P	14.19^a	11.55^b	11.08^b	8.75^c
C/P	493.72^a	814.14^b	513.98^c	798.21^d
Lignin/P	289.65^a	441.55^b	279.14^a	664.11^c

Values in parentheses denote standard error (n = 5). The values with similar letters across leaf and sheath categories were not significantly different at α=0.05.

Litter decay

In general, foliage decomposition patterns were similar for the two bamboo species (Fig. 1). However, in leaf litter of *P. bambusoides*, the rate of decomposition was higher up to 60 days of incubation (0.64% weight loss per day), and it became smaller through the next 60 days. The rate increased again through 180 days of incubation. Rapid decay in the other three litter categories was observed up to 120 days of incubation (0.41% to 0.56% weight loss per day), followed by a decline up to 240 days. After 180 days, both species showed similar patterns of decomposition, and the rates of mass loss were very slow through the end of the study. Moreover, net weight loss rate was higher in leaf litter of *P. bambusoides*, while in other litter types the rate was almost similar (Table 3). The undecomposed litter at the end of the study was the lowest for *P. bambusoides* (8.4%), compared to about 9.2%–9.6% for *A. racemosa*. The decay constant was significantly higher for *P. bambusoides* litter.

Table 3. Annual dry matter decay and nutrient release constants

Decay parameter	*P. bambusoides* Leaf	*P. bambusoides* Culmsheath	*A. racemosa* Leaf	*A. racemosa* Culmsheath
Dry matter decay				
% mass loss·d^{-1}	0.382	0.378	0.378	0.377
k (a^{-1})	3.76	3.61	3.58	3.54
t_{50} (d)	67.28	70.00	70.71	71.44
t_{99} (d)	485.44	505.05	510.2	515.46
N release				
% release·d^{-1}	0.380	0.378	0.378	0.412
k_N (a^{-1})	3.72	3.61	3.61	3.43
t_{50} (d)	67.94	70.00	70.00	73.72
t_{99} (d)	490.20	505.05	505.05	531.91
P release				
% release·d^{-1}	0.398	0.374	0.384	0.375
K_P (a^{-1})	4.67	3.47	3.87	3.50
t_{50} (d)	54.14	72.95	65.38	72.19
t_{99} (d)	390.63	526.32	471.70	520.83

Nutrient release

N concentration from 0–60 days declined in all litter categories. For both species, N concentration fluctuated over time, and at the end increased again, exceeding the initial concentration level. On the other hand, after 60 days of incubation, the N concentration in sheaths increased consistently up to 180 days and then declined (Fig. 2a). In both species, N mineralization and immobilization rates differed over time (Fig. 3a). After rapid mineralization up to 60 days, there was a tendency of N immobilization until 120 days except for the sheath litter of *A. racemosa*, and N immobilization continued till 180 days. Thereafter, mineralization occurred through the end of the incubation period. N release rates were slightly higher in *P. bambusoides* (k_N = 3.72 and 3.61

per year) than in *A racemosa* (k_N = 3.61 and 3.43 per year) (Table 3)

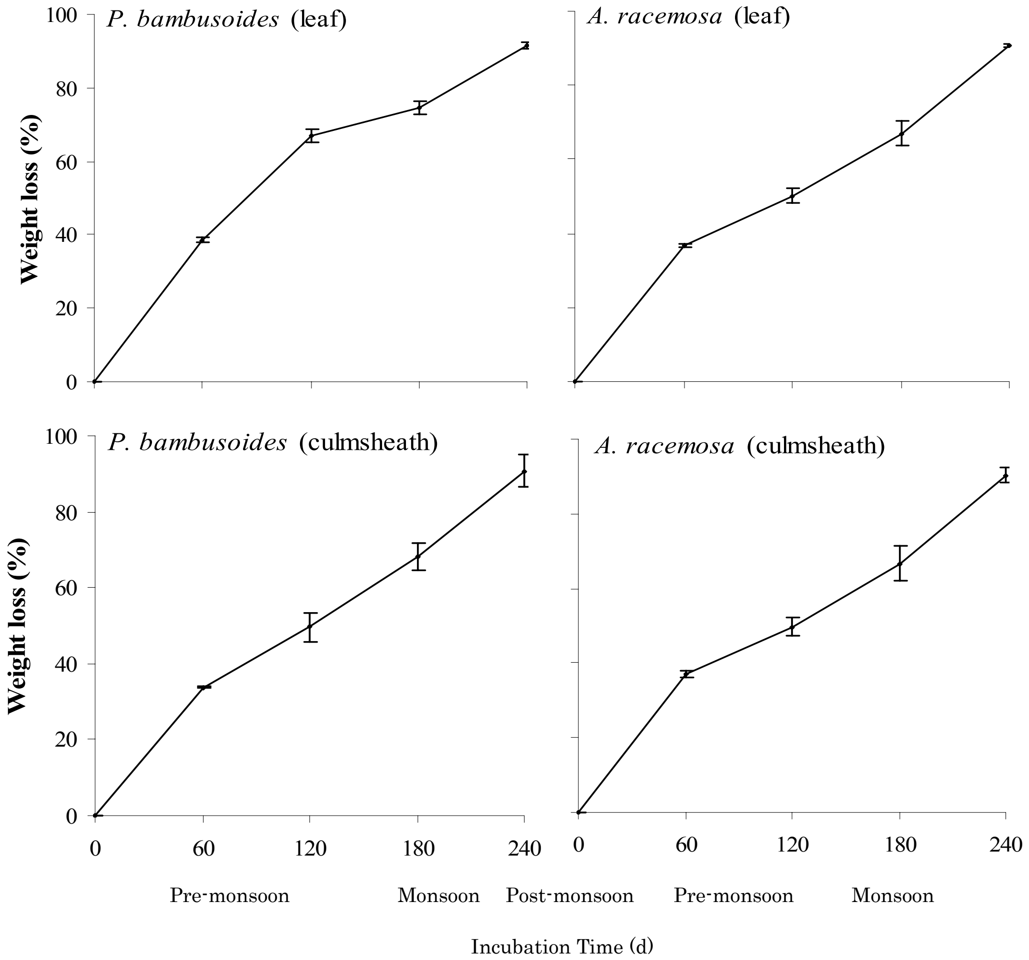

Fig. 1 Weight loss (%) during litter decomposition

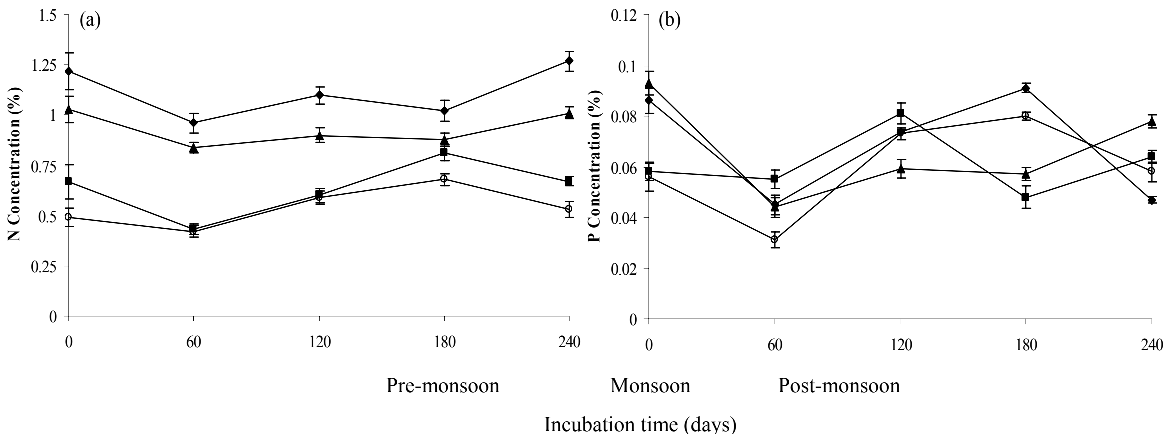

Fig. 2 N (a) and P (b) concentration (%) during litter decomposition of *P. bambusoides* ((♦) leaf, (■) sheath) and *A. racemosa* ((▲) leaf, (○) sheath)

In both species, P concentration decreased until 60 days of incubation (Pre-monsoon period). However, after 60 days, it increased rapidly in leaf litter of *P. bambusoides* and sheath litter of *A. racemosa* through 180 days. Thereafter, P concentration declined again (Fig. 2b). The other two litter categories followed similar trends as seen for N concentration of leaf litter of the same bamboo species. In general, P release patterns varied by species and litter type. During the initial 60 days of incubation,

rapid mineralization of P was observed in all litter categories. Except for leaf litter of *P. bambusoides*, P immobilization occurred during early monsoon (60–120 days), followed by rapid increase in P release rates. However, P immobilization was noticed during late monsoon (120–180 days) in *P. bambusoides* leaf litter (Fig. 3b). Also, from leaf litter of the same species P release was faster (k_P = 4.67 per year) for *A. racemosa* (3.87 per year). However, sheath litter did not differ significantly in P release rates (Table 3). Over all, the rate of P release was higher from leaf litter than from sheath litter for both species.

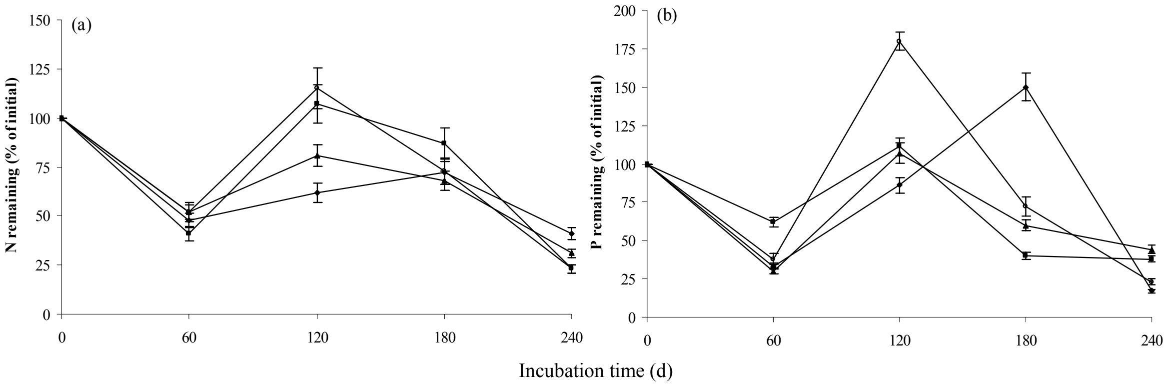

Fig. 3 N (a) and P (b) remaining (% of initial) during litter decomposition of *P. bambusoides* ((♦) leaf, (■) sheath) and *A. racemosa* ((▲) leaf, (○) sheath).

Effect of litter quality on decomposition and nutrient release pattern

For both species, strong positive correlations were documented between nitrogen and N/P with weight loss. However, C/N ratios showed significant negative correlation (p<0.01) with weight loss. Overall, lignin/N was negatively correlated with decay rate (Table 4).

In both species, only lignin concentration showed strong positive correlation with N release. N and P concentrations, in contrast, were negatively correlated with N release rate. However, both N and P concentrations were positively correlated with P release (Table 4).

Table 4. Relationships of decomposition rate (% weight loss·day^{-1}) and N and P release rates (% of initial·d^{-1}) with its initial chemical composition.

Variable	Decomposition		N release		P release	
	Correlation coefficient (*r*)	P	Correlation coefficient (*r*)	P	Correlation coefficient (*r*)	P
Lignin (%)	-0.585	0.01	0.992	0.01	-0.511	0.01
C (%)	-0.703	0.01	-0.284	NS	-0.638	0.01
N (%)	0.829	0.01	-0.696	0.01	0.923	0.01
P (%)	0.540	0.01	-0.590	0.01	0.767	0.01
Cellulose (%)	-0.590	0.01	0.064	NS	-0.273	NS
Fibre (%)	-0.648	0.01	0.189	NS	-0.331	NS
Lignin/N	-0.682	0.01	0.941	0.01	-0.692	0.01
C/N	-0.801	0.01	0.781	0.01	-0.875	0.01
C/P	-0.678	0.01	0.519	0.01	-0.881	0.01
N/P	0.932	0.01	-0.754	0.01	0.825	0.01
Lignin/P	-0.637	0.01	0.899	0.01	-0.708	0.01

NS, not significant. n = 20 (2 species × 2 residue types × 5 replicates)

Discussion

Initial litter quality and drymatter dynamics

In general, N and P concentrations in bamboo litter were comparable with ranges reported for other bamboo species (Virtucio et al. 1994; Deb et al. 2005; Tripathi et al. 2006; Nath and Das 2011). Lignin concentrations of two bamboo species studied here were well within the range (20.4–31.2) reported for other bamboo species (Arunachalam et al. 2005; Deb et al. 2005; Tripathi et al. 2006; Nath and Das 2011). However, the litter of the two bamboo species studied here were of poor quality with C/N>25. Myers et al. (1994) observed that litter with C/N<25 was of bet-

ter quality and decomposed at faster rates. The rate of weight loss of bamboo litter in the present study was faster (as indicated by higher annual decay constants, 3.54 to 3.76) than reported by Tripathi and Singh (1992a) for bamboo litter (0.43–2.76) in dry tropical bamboo savannas, Fu et al. (1988) for bamboo timber-stands in China (0.41–0.71), Liu et al. (2000) for *Sinarundinaria nitida* in China (0.40), Sujatha et al. (2003) for *Ochlandra travancorica* in Western Ghats, India (0.23), Tripathi et al. (2006) for *Sasa kurilensis* leaf litter (0.21) in temperate forests of northern Japan, Das and Das (2010) for *Bambusa cacharensis* (1.34) in humid tropics of India, and Nath and Das (2011) for *B. cacharensis* (1.31−1.44), *B. vulgaris* (1.21−1.71), and *B. balcooa* (1.07−1.64) in subtropical homegardens of northeast India. Conversely, Arunachalam et al. (2005) reported faster rates of decomposition for *B. balcooa* (k=5.84) and *B. pallida* (k=8.03) in humid tropical forests of Arunachal Pradesh, India. However, the decay constants in our study were similar to those for *Bambusa tulda* (3.52) and *Dendrocalamus hamiltonni* (3.38) reported by Deb et al. (2005) in the humid foothills of the same region. Overall, we suggest that the leaf and sheath litter of the two bamboo species studied here follow similar decomposition patterns. However, initial decay rates in these highland bamboo species studied are higher than the lowland bamboo species reported in the region (Arunachalam et al. 2005), possibly due to higher initial N concentrations in the former. Besides litter quality parameters, climate might influence the decay process significantly, as suggested by Dyer et al. (1990) and Austin and Vitousek (2000). They noted that bamboo litter in warmer tropical areas decomposes faster than in cooler and temperate areas.

Contrary to earlier reports (Deb et al. 2005; Nath and Das 2011), we documented faster rates of decomposition during the initial 120 days of incubation. Our litter samples were buried during late March, when the soil temperature after severe cold gradually increases, creating favourable conditions for rapid colonization by soil microbes and hence a higher decay rate in these sites during post-winter incubation period. Tripathi et al. (2006) also observed significantly faster relative decomposition rates for *Sasa kuriliensis* during the early period in northern temperate forest of Japan.

The C/N ratio of plant litter has frequently been negatively correlated with decomposition rates (Edmonds 1980; Taylor et al. 1989; Tripathi et al. 2006). We also observed such a relationship. Among other litter quality parameters, initial N and lignin concentrations influenced the litter decay pattern (Vogt et al. 1991; Tripathi and Singh 1992a; Arunachalam et al. 1996; Liu et al. 2000; Deb et al. 2005). For instance, the faster decay of leaf litter compared to sheath litter we attribute to greater initial N in the former (Table 2). Similar to most reports (Blair 1988; Tripathi and Singh 1992a; Arunachalam et al. 1996; Torreta et al. 1998; Nath and Das 2011), we found a negative correlation between initial lignin concentration, lignin/N ratio, C/N ratio and rate of weight loss during decomposition. This was similar to the conclusion of Enriquez et al. (1993) that greater initial P concentration led to faster decomposition. We observed a positive correlation between initial P and decay rates. However, further work needs to be done to test this hypothesis, for a better understanding of the role of P in the regulation of litter decomposition.

Nutrient dynamics

N dynamics

Apart from leaching, optimum temperature and moisture levels in soil during the early decomposition period might result in rapid release of N from the litter of *P. bambusoides* and *A. racemosa*. But during the monsoon, N concentrations in the decomposing leaf litter increased due to intense immobilization activity of microbes, under the most favourable climatic conditions, coupled with rapid decomposition of organic matter compared with the release of nitrogen (Deb et al. 2005). *P. bambusoides* is a highly managed bamboo species at our study site, where harvesting of mature bamboos (3-4 times a year) and other cultural operations are carried out (weed and climber cutting, heaping slash inside the plantation after harvesting) in the stands during the post-monsoon period till March. This might have contributed to enhanced immobilization during the post-monsoon period. However, greater C/N and lignin/N may be responsible for protracted immobilization in *A. racemosa* litter as suggested by Tripathi and Singh (1992b), Upadhyaya and Singh (1989), and Tripathi et al. (2006). On the contrary, we found strong positive correlation between lignin/N and C/N ratio and N release. Also, significant positive correlation between lignin and negative correlation between initial N concentration and N release suggests that climatic variables rather than litter quality parameters might have more pronounced effects on N release of highland bamboo species. In general, mineralization was more prominent in the bamboo species studied than that of the many species reported earlier (Arunachalam et al. 2005; Deb et al. 2005; Tripathi et al. 2006; Nath and Deb 2011). This pattern is also in consistent with the findings of Garkoti and Singh (1999) on a decomposition study conducted in a high altitude forest ecosystem in the Central Himalaya.

P dynamics

In the initial decomposition stages (0–120 days), P release in decomposing litter decreased or increased depending upon the initial P content of litter (Fig. 2b and 3b). Shorter or longer P immobilization periods were reported by Stohlgren (1988) and Prescott et al. (1993) for a variety of litter samples. Moreover, P immobilization observed in the present study may be found in the litter samples because of high C/N ratios. Organic litter with C/N ratio<25 are of good quality and they release nutrients at a faster rate compared to low quality litter (C/N>25) (Myers et al. 1994). In this case, the classic pattern of nutrient immobilization followed by release was always more conspicuous for fast decomposing litter than for litter decaying more slowly (Rustad and Cronan 1988). This may also be explained by the role of "critical" P content in non-woody litter, and above "critical" P content P is released, as suggested by Prescott et al. (1993), Rustard and Cronan (1988) and Eason and Newman (1990). In our study, initial concentration of P and C/P ratios in litter samples were found to be good predictors of P release as evinced by the significant positive and negative correlations, respectively (Table 4).

Other litter quality parameters, *viz*.: C/N, lignin/N and N, showed significant relationships with P release. In this regard, the observations made by Tripathi and Singh (1992b) for bamboo litter (*Dendrocalamus strictus*) in a dry tropical savanna in northern India, are similar to our findings.

Overall, nutrient mineralization is a prominent process during the decomposition of bamboo litter. The litter fractions in this study were all of low quality (C/N=34–47 for leaf litter and 70–92 for sheath), which may have also influenced nutrient dynamics during decomposition. Despite variations in N and P concentrations due to release and/or immobilization, N and P stocks remaining in the litter were positively correlated to its dry mass ($r = 0.49$, $p<0.05$ for N and $r = 0.67$, $p<0.01$ for P). Cotrufo et al. (1999) reported no evidence for any increase in nutrient content in the litter, although the nutrient concentration increased owing to immobilization.

Conclusion

The research result reflects that litter decomposition and N release pattern are similar between two bamboo species, whereas, P release from leaf litter was faster in *P. bambusoides* and differed significantly between the sheath and leaf litter for both species. The slower release of P from leaf litter of *A. racemosa* may be a nutrient conservation strategy of species growing in highly acidic phosphorous deficient soils. Weight loss was strongly positively correlated with N and N/P ratios, and significantly negatively correlated ($p<0.01$) with C/N and Lignin/N ratio. Most of the litter quality parameters showed significant relationships with N and P release. The complex pattern of nutrient release through mineralization and immobilization during decomposition ensures nutrient availability in both managed and natural bamboo stands in the region subjected to anthropogenic disturbances.

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